BIDIRECTIONAL REFLECTANCE OF ASTEROID SURFACE ANALOGUES: QUANTIFICATION OF POROSITY AND SURFACE ROUGHNESS. T. Sakai, N. Tomita, and A. M. Nakamura, Graduate School of Science and Technology, Kobe University, 1-1 Rokkodai, Nada, Kobe, Japan, tacchan@harbor.scitec.kobe-u.ac.jp

Introduction: Laboratory photometric phase curves of meteorite powders give constraints on the meteorites-asteroids connections, as well as the surface structure of asteroids. We performed laboratory measurements of bidirectional reflectance of meteorite powders with the sample surfaces smoothed by spatula[1][2][3]. The results were as follows: the surfaces of meteorite powders showed shallower phase curves than those of most asteroids, and those made of carbonaceous chondrite-powders were about one-half or twice brighter than asteroid 253 Mathilde, although the wavelength of the measurements was not exactly the same as asteroid observations. The real surface of asteroids is naturally be rougher than those prepared in the laboratory. Here we report the results of our study on the bidirectional reflectance of powdery surfaces of artificial materials and an ordinary chondrite meteorite with various surface structures.

Instrumentation: We used a goniometric setting at Kobe University which has two arms. The arms can rotate in the upper-half plane normal to the sample surface and are equipped with a He-Ne laser source (wavelength 633 nm) and a photo-multiplier, respectively. We measured the intensity of the laser light reflected by the sample surface, with the emergent angle (***e***) being changed but the incident angle (***i***) being fixed at 0 degree. The absolute reflectance r(***i***, ***e***, ***g***), where ***g*** denotes phase angle, was determined using a reflectance standard of a Ba_2SO_4 surface[1].

Powdery Samples: We used fly ash (SiO_2 45%), iron and graphite powders for porosity, roughness, and reflectance measurements. Powders of NWA539 (LL3.5) meteorite were used for roughness and reflectance measurements. The diameter or maximum length of the powder grains was typically 2µm (fly ash), below 6 µm (iron), below 45µm (graphite), and 5-20µm, 45-75µm, and 180-500µm (NWA539)[2] . The target surfaces were made by these powders, varying the porosity (**P**) of the powdery layer. The fluffy surfaces ("fluffy") were made only by sieving the powders over the sample trays. The intermediately porous surfaces ("knocked") were made from the fluffy ones by knocking the sample trays vertically against a horizontal plane. The smooth surfaces were made by either compacted tightly ("compact") or leveled by a spatula ("flattened"). The "fluffy" and "knocked" surfaces were not touched directly.

To calculate the porosity of a powdery layer, we measured 1) capacity of the target tray and 2) the total mass of the powders filled in the tray, so we can estimate the volume of the opening space between the particles using the specific density of the powder materials, and calculate the bulk porosity. The roughness of the surface was determined by calculating the mean slope angle <***θ***> of small local facets of the surface. The slope angle of the each facet was determined from the altitude of the surface measured at certain horizontal pitch [4] .

Table 1. Bulk porosity and surface roughness of the artificial powders. The standard deviation of the slope angle is shown in the columns of $\Delta\theta$.

Samples		P	1µm pitch		10µm pitch	
			<***θ***>	$\Delta\theta$	<***θ***>	$\Delta\theta$
Fly ash	compact	0.37	41.0	21.0	8.8	7.8
	knocked	0.45	48.0	20.0	23.0	15.0
	fluffy 2	0.86	71.0	15.0	57.0	17.0
	fluffy 1	0.88	69.0	19.0	56.0	18.0
Iron	compact 2	0.45	15.0	13.0	3.6	2.9
	compact 1	0.50	18.0	14.0	4.2	4.1
	fluffy	0.73	61.0	18.0	48.0	17.0
Graphite	compact	0.67	39.0	21.0	13.0	11.0
	knocked 1	0.67	52.0	21.0	22.0	15.0
	knocked 2	0.83	62.0	20.0	35.0	18.0
	fluffy	0.89	71.0	16.0	49.0	20.0

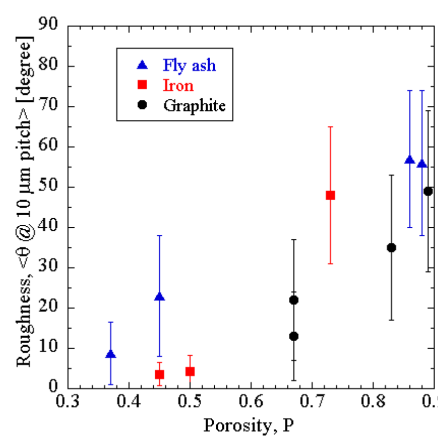

Figure 1. Surface roughness versus bulk porosity.

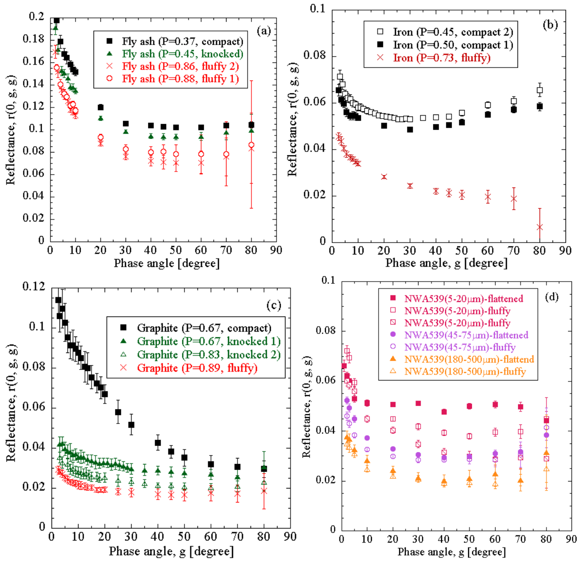

Figure 2. Bidirectional reflectance of powdery surfaces of (a) fly ash, (b) iron, (c) graphite, and (d) ordinary chondrite, NWA539.

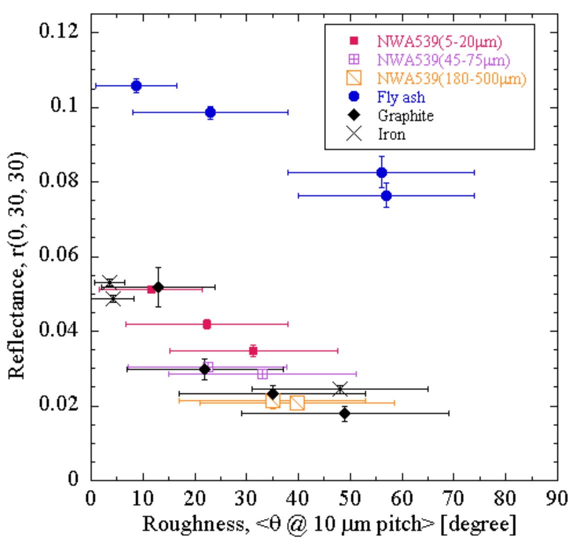

Figure 3. Bidirectional reflectance at g=30 degree versus surface roughness.

Results: Table 1 summarizes the bulk porosity together with the surface roughness of the of artificial materials. The roughness measured at 1µm pitch is larger than that at 10µm; the similar tendency was shown in previous studies[3][4]. In general, the roughness of the surface increases systematically with the bulk porosity of the layer as shown in Fig. 1. In this figure, there are two graphite points at **P**=0.67; upper point (<θ>=22 degree) and lower point (<θ>=13 degree) denote "knocked" and "compact" surfaces, respectively (see Table 1 and Fig. 2(c)). This fact displays that the surface roughness can have a range even with the same bulk porosity.

Figures 2(a)-(d) show bidirectional reflectance of the samples. As the surface roughness, that is, the bulk porosity in the present case increases, the reflectance at larger phase angle, where the effect of the opposition surge is weak or negligible, becomes lower as Capaccioni et al. (1990)[5] showed qualitatively. The varieties of this effect can be seen among the powdery materials and phase angles. The fly ash and the meteorite surfaces show nearly equivalent decrease of reflectance in any phase angles, except for those near 0 degree (Fig. 2(a)), whereas the iron surfaces show conspicuous differences at high phase angle (Fig. 2(b)). Contrary to the others, the graphite surfaces show larger discrepancy rather at low phase angle.

In Figure 3, a negative correlation between the surface roughness, in terms of the mean slope angle, and the reflectance is shown. The pairs of meteorite surfaces of medium (45-75µm) and large (180-500µm) size-particles show less difference both in reflectance and surface roughness. This is probably because the particles with these sizes can hardly form a porous structure under the 1G gravity and the porosity has more effect on bidirectional reflectance of particles with smaller size comparable to the wavelength of the light.

Discussion: We have shown that the reflectance of powdery surface is greatly influenced by the surface structure and there is a systematic relation between bulk porosity and surface roughness. The sample surface must be carefully treated in light-scattering measurements of powdery samples when it is performed for the purpose of a comparison with asteroid surfaces.

Further investigation of the effect of the surface structure on bidirectional reflectance with different incident angle would at least partly explain the shallower phase curve of the meteorite surfaces obtained in the laboratory and provide new information of absolute reflectance of the surface of meteorite powders. This work will be useful in analyzing the sedimentary condition of regolith on small bodies in terms of the bidirectional reflectance retrieved by instruments on spacecrafts and collected regolith samples in future sample-return missions.

References: [1] Kamei A. and A. M. Nakamura (2002) *Icarus, 156*, 551–561. [2] Tomita N. and A. M. Nakamura (2002) *LPS XXXIII*, Abstract #1100. [3] Nakamura A. M. et al. (2002) *Mem. Italian Astron. Soc., 73*, 722-725. [4] Tomita N. et al. (2002) *Mem. Italian Astron. Soc., 73*, 739-742. [5] Capaccioni, F. et al. (1990) *Icarus, 83*, 325-348.